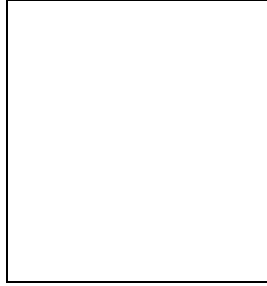


The First RHIC Spin Run—at PHENIX and PP2PP

Gerry Bunce^a

*Physics Department and RIKEN BNL Research Center, Brookhaven National Laboratory
Upton, NY 11973-5000, USA*



The RHIC spin program will probe the spin structure of the proton with polarized quarks and gluons by colliding beams of polarized protons at Brookhaven. The first collisions, at $\sqrt{s}=200$ GeV, were recorded this year in December 2001 and January 2002. This report describes the first run, and our plans for the next five+ years, with planned runs at $\sqrt{s}=200$ and 500 GeV, and luminosity $L=2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$. See also the presentation at Moriond by Bernd Surrow on the first run with the STAR detector. Here we include a first look at measurements with the PHENIX and PP2PP detectors.

1 Introduction

The spin program of the Relativistic Heavy Ion Collider (RHIC) at BNL collides polarized proton beams from $\sqrt{s} = 50$ GeV to 500 GeV, with expected luminosity of $L = 2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ for the top energy collisions. At these energies and luminosity, the collisions at high transverse momentum can be described as collisions of polarized partons, quarks and gluons, where the polarized quarks and gluons of the protons in one beam probe the spin structure of the protons in the other beam. RHIC spin provides a new laboratory to study the proton, compared to earlier and ongoing extensive studies of nucleon spin structure using polarized lepton beams incident on polarized proton and neutron targets. The earlier lepton studies gave us the major surprise that on average only about 25% of the proton spin is carried by the quarks and antiquarks in the proton. Since the lepton experiments probe the nucleon via a virtual photon, these *deep inelastic* lepton experiments are sensitive to the quark distributions through electric charge, and are not directly sensitive to the gluon contribution to the proton spin. With the strongly interacting quark and gluon probes at RHIC, a major focus of our program is to measure the gluon polarization through the *deep inelastic* scattering of polarized quarks from polarized protons. Reference¹ previews the RHIC spin program.

^abunce@bnl.gov

The cross section for the collision of high energy polarized protons, producing particles at large p_T , factorizes similarly to the perturbative QCD description of unpolarized proton-antiproton collisions at the Tevatron, for example. When an asymmetry is formed by comparing the cross section for particles produced for collisions of protons with the same helicities, with the cross section for particles produced for differing beam helicities, we can directly measure the proton spin structure.

We will now describe the first RHIC spin run.

2 Accelerating and Measuring Polarization

A schematic of the RHIC spin complex is shown on the left side of Figure 1. Each independent RHIC ring, referred to as the blue and yellow rings, was loaded in this first run with 55 bunches of polarized protons, at 24 GeV, and then accelerated to 100 GeV. The bunches were loaded with different patterns of alternating polarization sign, with three bunches with zero polarization, so that the collisions at the experiments included the combinations $(++,+-,-+,-,-,00)$ where the signs refer to (blue,yellow) polarization sign for the colliding bunches.

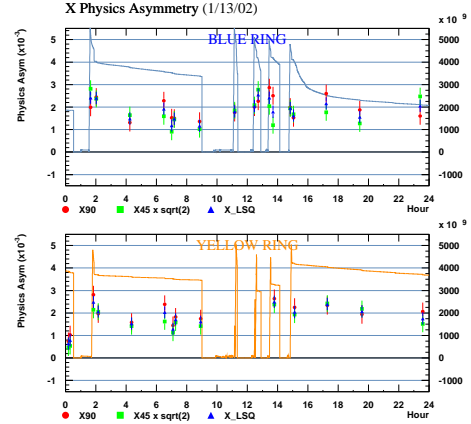
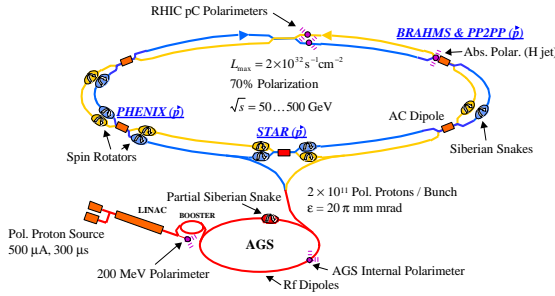


Figure 1: Schematic of the RHIC spin accelerator complex (top) and measurements of the polarization with the beam intensity overlaid (bottom). For the figure on the right, the solid lines record the intensity in RHIC, referring to the axis on the right side of the figure. Independent polarimeter measurements of the asymmetry are shown as data points, referring to the axis on the left side of the figure.

The polarization was measured using separate polarimeters in the blue and yellow rings, which scattered the polarized protons from an ultra-thin carbon ribbon which could be inserted into the RHIC beams. Scattering in the coulomb-nuclear interference region is sensitive to the polarization, and the right side of Figure 1 shows the measured asymmetries from the polarimeters, along with the beam intensities, for a several hour period. Several RHIC fills are seen in the figure. When the intensity is seen to rise, the RHIC ring is being filled with 55 bunches at 24 GeV. An asymmetry measurement just after filling is made at injection energy. During the acceleration to 100 GeV, some beam is lost and the intensity is seen to reduce. Measurements of the asymmetry are then made, typically every 2 hours, on the stored 100 GeV beams. When we compare the polarization measurements at 24 GeV, before acceleration, and at 100 GeV, the asymmetry is comparable. This is the first use of Siberian Snakes at high energy, and the polarization was maintained for acceleration through roughly 150 depolarizing resonances up to 100 GeV, with no adjustment to the Snakes. The polarization, using the analyzing power from 24 GeV, was 20% for this run.

3 The Physics of the First Run: PHENIX and PP2PP

The first run, completed this January, 2002, collided transversely polarized protons at $\sqrt{s} = 200$ GeV, $L = 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$, $P = 0.2$. Experiments measured cross sections and asymmetries for mid-rapidity and forward pion production, for proton-proton small angle elastic scattering. Bernd Surrow, in his presentation on the STAR experiment, discusses forward production. Here, we will present mid-rapidity and elastic scattering.

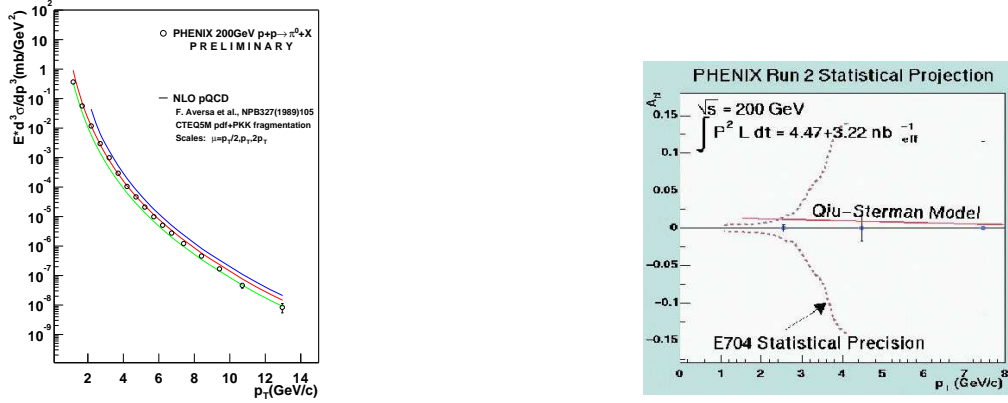


Figure 2: Preliminary π^0 cross section vs. p_T at mid-rapidity from the PHENIX Collaboration, with a published pQCD NLO calculation overlaid (left); and the expected sensitivity for the asymmetry A_N for π^0 (right). The dashed lines on the right side indicate the size of the error bars on an earlier fixed target experiment from Fermilab at much lower energy.

Measurements of the transverse spin asymmetry A_N probe the transverse spin structure of the proton. Measurements were made for π^0 s and charged hadrons by PHENIX, for colliding transversely polarized protons. The PHENIX Experiment is one of the two large heavy ion/spin detectors at RHIC². The experiment is a fast detector, featuring excellent photon and electron calorimetry at mid-rapidity, with tracking and RICH detectors, and muon arms in the forward direction from each beam. The electromagnetic calorimeters at mid-rapidity were used in the pp run to trigger on energy clusters above 1 GeV, and a large sample of high- p_T π^0 s were collected. Figure 2, left, shows the PHENIX Preliminary result for the π^0 cross section vs. p_T ³. Also shown on the left figure is a perturbative NLO QCD calculation for the cross section⁴, with three factorization scales. This is not a fit. The agreement of the theory with the data shows that pQCD properly describes the production of pions at mid-rapidity at RHIC. This is important to the RHIC spin program, since it is the interpretation of pp scattering with factorization and pQCD which will allow us to extract information on the spin structure of the proton at RHIC. We note also the good agreement down to $p_T=2$ GeV/c, and the relatively small dependence on the factorization scale.

The right side of the figure shows the expected statistical significance of the measurement of the single spin transverse asymmetry A_N . The figure shows sensitivity at a 1% level. An asymmetry observed by the HERMES⁵ and SMC⁶ experiments, interpreted as transversity, would imply an of order 10% asymmetry at RHIC⁷. Also shown are dashed lines giving the error sizes vs. p_T for a previous mid-rapidity measurement at much lower energy, E704 at Fermilab⁸. The theoretical model shown⁹ is for a higher twist effect, from quark-gluon correlations in the proton. This mid-rapidity measurement will probe a qualitatively new physics region for spin, in both energy and transverse momentum.

The PP2PP Experiment¹⁰ uses devices called Roman Pots to move silicon detectors close to the beams, after the beams are stored in RHIC. The experiment measures pp elastic scattering in the coulomb, coulomb-nuclear interference (CNI), and low to mid-t regions. In this run,

the experiment used a 1-day store where the RHIC beams were severely scraped to reduce their emittance to allow the experiment to make measurements in the CNR region, for $-t > 0.004 (\text{GeV}/c)^2$. These are the first pp measurements for $\sqrt{s} = 200 \text{ GeV}$, and the first for spin. Figure 3 shows a schematic of the location of the Roman Pots, left, and on the right side shows the observed correlation between the scattered proton position in one silicon detector near one beam vs. the scattered proton position for the other beam. This on-line result is remarkably clean, and the experiment expects to obtain the t -dependence and asymmetry A_N from the run.

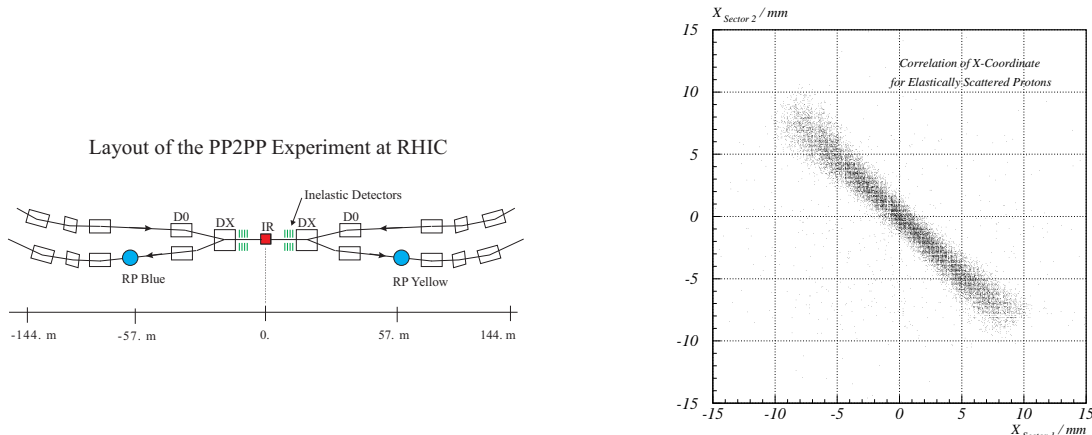


Figure 3: *PP2PP Experiment layout (left) and the observed correlation between the scattered protons in each beam as seen in silicon detectors near the beams (right).*

4 Plan and Conclusions

The gluon polarization will be measured at RHIC using direct photons, photon plus jet, and jets. Anti-quark and quark polarizations will be measured, identified by flavor, using parity-violating W boson production. These are the major focus of the RHIC spin program.

There are many other processes and probes planned. For the coming year, when luminosity, polarization and running time will still be at a premium, jet production should provide a first look at gluon polarization. Other processes are heavy quark production with spin, transversity measurements, fragmentation processes with spin, searches for new physics using parity violation, and many others. The program, described in ¹, is expected to take 5+ years of RHIC running, which consists of both heavy ion and polarized proton modes. This schedule does not include follow-on experiments to pursue exciting signals and new ideas.

We have important issues to solve to reach our goals: higher polarization and luminosity, and absolute calibration of the RHIC polarimeters. The polarization from the AGS was very low in our first run. To improve this, we will be using a much faster ramp rate in the AGS next year. We are building a fast polarimeter for the AGS based on the RHIC polarimeters to improve our identification of problem areas. We are also designing a new strong AGS partial Siberian Snake, available for 2005. For the luminosity, we need to gain a factor of 100 over this first run. Many of the anticipated improvement factors are straight forward, such as a factor 3 improvement using focusing at the interaction regions with $\beta^* = 1$, already used for heavy ions, and a factor 2 from doubling the number of bunches. We will see.

In summary, the polarized proton program at RHIC has begun, we have some beautiful data, and we have a long, exciting road ahead.

References

1. G. Bunce, N. Saito, J. Soffer and W. Vogelsang, *Ann. Rev. Nucl. Part. Sci.* **50** (2000) 525.
2. PHENIX Collaboration, D.P. Morrison et al., *Nucl. Phys.* **A638** (1998) 565.
3. H. Torii for the PHENIX Collaboration, *Quark Matter 2002*, Nantes, France.
4. F. Aversa et al., *Nucl. Phys.* **B327** (1989) 105; parton distributions from CTEQ5M, H. Lai et al., *Eur. Phys. J.* **C12** (2000) 375; fragmentation distribution from B. Kniehl et al., *Nucl. Phys.* **B582** (2000) 514.
5. Airapetian A. et al., *Phys. Rev. Lett.* **84** (2000) 4047. We thank W. Vogelsang for preparing the theory prediction for us.
6. A. Bravar, *Nucl. Phys. Proc. Suppl.* **B79** (1999) 520.
7. M. Anselmino and F. Murgia, *Phys. Lett.* **B483** (2000) 74; M. Anselmino et al., *Nucl. Phys. Proc. Suppl.* 105 (2002) 122.
8. D. Adams et al. (E704 Collaboration), *Phys. Lett.* B261 (1991) 201; *Phys. Lett.* **B264** (1991) 462.
9. J. Qiu and G. Sterman, *Phys. Rev.* D59 (1998) 014004.
10. W. Gury, *Nucl. Phys.* **B99** (2001) 299.